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PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Reissue Application of:

Hall et al.

U.S. Patent No.: 5,131,069 **Issued: July 14, 1992**

Serial No.: 07/743,726 **Group Art Unit: 2501**

Filing Date: August 12, 1991 **Examiner: Barns, S.**

For: FIBER AMPLIFIER HAVING MODIFIED GAIN SPECTRUM

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I hereby certify that this paper is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

Typed Name: Bob Inforzato

Assistant Commissioner for Patents
Washington DC 20231

Sir:

REISSUE APPLICATION TRANSMITTAL LETTER

Transmitted herewith is the application for reissue of U.S. Patent No. 5,131,069, issued on July 14, 1992.

Enclosed are the following:

1. SPECIFICATION, CLAIM(S) AND DRAWING(S)

X 8 page(s) of specification

X 3 page(s) of claims

X 1 page(s) of abstract

Note: This must include the entire specification and claims of the patent, with the matter to be omitted by reissue enclosed in square brackets; and any additions made by the reissue must be underlined, so that the old and new specifications and claims may be readily compared. Claims should not be renumbered and the numbering of claims added by reissue should follow the number of the highest numbered patent claim.

X 4 sheet(s) of ☐ formal / X informal drawings.

X No changes in the drawings upon which the original patent was issued are to be made. Therefore, in accordance with 37 C.F.R. § 1.174, please find attached, in the size required for original drawings:

- X a copy of the printed drawings of the patent.
- ☐ a photoprint of the original drawings.

2. DECLARATION AND POWER OF ATTORNEY

X 5 pages of declaration and power of attorney.

☐ Signed ☒ Unsigned

☐ An Associate Power of Attorney.

3. PRELIMINARY AMENDMENT (check if applicable)

X enclosed herewith.

4. OFFER TO SURRENDER THE ORIGINAL LETTERS PATENT IN ACCORDANCE WITH 37 C.F.R. § 1.178 IS ATTACHED

X Offer to surrender is by the inventor.

- X along with assent of assignee.

☐ Offer to surrender is by the assignee of the entire interest (and the reissue application does not seek to enlarge the claims of the original patent).

5. LETTERS PATENT

☐ Original letters patent attached.

☐ Declaration that original letters patent lost or inaccessible.

X Original letters patent or declaration that original letters patent lost or inaccessible will be submitted after prosecution on the merits but before the application has been allowed.

Note: "The application may be accepted for examination in the absence of the original patent or the declaration but one or the other must be supplied before the case is allowed." 37 C.F.R. § 1.178.

Note: "If a reissue be refused, the original patent will be returned to applicant upon his request." 37 C.F.R. § 1.178.

6. CONSENT OF ASSIGNEE AND ASSIGNEE'S INTEREST

In accordance with 37 C.F.R. §1.171(a), this application for reissue is accompanied by Consent of Assignee for Reissue and Assignee's Statement of Ownership Interest [37 C.F.R. §3.73(b)] with:

☐ Copy or copies of recorded documentary evidence of a chain of title from the original owner to the assignee.

X Designation by reel and frame where documentary evidence of a chain of title from the original owner to the assignee is recorded in the Office.

7. INFORMATION DISCLOSURE STATEMENT (check if applicable)

☐ attached.

8. PRIORITY - 35 U.S.C. § 119

☐ Priority of application Serial No. @@ filed on @@ in @@ (country) is claimed under 35 U.S.C. § 119.

☐ The certified copy has been filed in prior application Serial No. @@ filed on @@

9. FEE CALCULATION (37 C.F.R. §§ 1.16(h), (i) and (j))

			SMALL ENTITY		NOT SMALL ENTITY	
			RATE	FEE	RATE	FEE
			$395.00	$	$790.00	$790
	No. Filed	No. Extra				
TOTAL CLAIMS	50 - 20 <u>OR</u> the number of claims in original patent, whichever is greater =	30	$11 each	$	$22 each	$660
INDEP. CLAIMS	14 minus number of 5 independent claims in original patent =	9	$41 each	$	$82 each	$738
MULTIPLE DEPENDENT CLAIMS ARE TREATED AS ORDINARY CLAIMS FOR FEE PURPOSES. 37 C.F.R. §1.16(j).						
TOTAL FILING FEE DUE				$		$2188.00

10. SMALL ENTITY STATUS (if applicable)

Note: A new verified statement is required for the reissue even if one has been filed in the original patent.

☐ A Verified Statement Claiming Small Entity Status under 37 C.F.R. §§ 1.9 and 1.27 is enclosed.

11. METHOD OF PAYMENT OF FEES

X A check in the amount of **$2188.00** is attached. Please charge any deficiency or credit any overpayment to Deposit Account No. 23-3050.

☐ Please charge my Deposit Account No. 23-3050 in the amount of $.

12. AUTHORIZATION TO CHARGE ADDITIONAL FEES

☒ The Commissioner is hereby authorized to charge payment of the following fees associated with this communication or credit any overpayment to Deposit Account No. 23-3050.

☒ Any additional filing fees required under 37 C.F.R. §§ 1.16(a), (f) or

(g) (filing fees) including fees for presentation of extra claims (37 C.F.R. §§ 1.16(b), (c) and (d)).

☒ Any additional patent application processing fees under 37 C.F.R. § 1.17 and under 37 C.F.R. § 1.20(d).

☒ The Commissioner is hereby authorized to charge payment of the following fees during the pendency of this application or credit any overpayment to Deposit Account No. 23-3050.

☒ Any patent application processing fees under 37 C.F.R. § 1.17 and under 37 C.F.R. § 1.20(d).

☐ The issue fee set in 37 C.F.R. § 1.18 at or before mailing of the Notice of Allowance, pursuant to 37 C.F.R. § 1.311(b).

☒ Any filing fees under 37 C.F.R. § 1.16 including fees for presentation of extra claims.

This sheet is attached in triplicate.

Date: June 26, 1998

Francis A. Paintin

Francis A. Paintin
Registration No. 19,386

Woodcock Washburn Kurtz
Mackiewicz & Norris LLP
One Liberty Place - 46th Floor
Philadelphia PA 19103
Telephone: (215) 568-3100
Facsimile: (215) 568-3439

FIBER AMPLIFIER HAVING MODIFIED GAIN SPECTRUM

BACKGROUND OF THE INVENTION

The present invention relates to fiber amplifiers having means for selectively attenuating or removing unwanted wavelengths to modify or control the amplifier gain spectrum.

Doped optical fiber amplifiers consist of an optical fiber the core of which contains a dopant such as rare earth ions. Such an amplifier receives an optical signal of wavelength λ_s and a pump signal of wavelength λ_p which are combined by means such as one or more couplers located at one or both ends of the amplifier. The spectral gain of a fiber amplifier is not uniform through the entire emission band.

The ability to modify the gain spectrum of a fiber amplifier is useful. Three modifications are of interest: (1) gain flattening, (2) changing the gain slope, and (3) gain narrowing. Gain flattening is of interest for such applications as wavelength division multiplexing. A change in the gain slope can be used to reduce harmonic distortion in AM modulated optical systems (see A. Lidgard et al. "Generation and Cancellation of Second-Order Harmonic Distortion in Analog Optical Systems by Interferometric FM-AM Conversion" IEEE Phot. Tech. Lett., vol. 2, 1990, pp. 519–521) Gain narrowing is of interest because although the amplifier can be operated at wavelengths away from the peak gain without gain narrowing, disadvantages occur due to: increased spontaneous-spontaneous beat noise, a reduction in gain at the signal wavelength because of amplified spontaneous emission at a second wavelength (such as at 1050 nm in a Nd fiber amplifier designed to amplify at 1300 nm), and possible laser action at the peak gain wavelength.

Various techniques have been used for flattening the gain spectrum. An optical notch filter having a Lorentzian spectrum can be placed at the output of the erbium doped gain fiber to attenuate the narrow peak. A smooth gain spectrum can be obtained, but with no increase in gain at longer wavelengths.

Another filter arrangement is disclosed in the publication, M. Tachibana et al. "Gain-Shaped Erbium-Doped Fibre Amplifier (EDFA) with Broad Spectral Bandwidth", Topical Meeting on Amplifiers and Their Applications, Optical Society of America, 1990 Technical Digest Series, Vol. 13, Aug. 6–8, 1990, pp. 44–47. An optical notch filter is incorporated in the middle of the amplifier by sandwiching a short length of amplifier fiber between a mechanical grating and a flat plate. This induces a resonant coupling at a particular wavelength between core mode and cladding leaky modes which are subsequently lost. Both the center wavelength and the strength of the filter can be tuned. The overall gain spectrum and saturation characteristics are modified to be nearly uniform over the entire 1530–1560 nm band. By incorporating the optical filter in the middle of the erbium doped fiber amplifier, the amplifier efficiency is improved for longer signal wavelengths.

SUMMARY OF THE INVENTION

An object of the present invention is to further improve the efficiency of a fiber amplifier and/or tailor the spectral output of a fiber amplifier.

The present invention relates to a fiber amplifier having spectral gain altering means. Fiber amplifiers con-

ventionally comprise a gain optical fiber having a single-mode core containing gain ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p. Means are provided for introducing a signal of wavelength λ_s and pump light of wavelength λ_p into the gain fiber. In accordance with this invention, the fiber amplifier is provided with absorbing ion filtering means for attenuating light at at least some of the wavelengths within the predetermined band of wavelengths including the wavelength λ_s.

In accordance with a first aspect of the invention, the absorbing ion filtering means comprises unpumped gain ions; this embodiment requires means for preventing the excitation of the unpumped gain ions by light of wavelength λ_p. In accordance with a further aspect of the invention, the absorbing ions are different from the rare earth gain ions of gain fiber.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of a fiber amplifier in accordance with the present invention.

FIG. 2 is a graph showing the gain spectra of an erbium-aluminum-doped germania silicate fiber amplifier.

FIG. 3 is a schematic illustration showing a first aspect of the invention.

FIG. 4 is a schematic illustration of an embodiment wherein pump light attenuating means is in series with the gain fiber;

FIG. 5 is a graph illustrating the spectral transmission characteristic of an unpumped erbium-aluminum-doped germania silicate fiber that can be employed in the embodiment of FIG. 4.

FIGS. 6 and 7 are graphs showing gain spectra and spectral transmission for a further mode of operation of FIG. 4.

FIG. 8 illustrates a fiber amplifier in which the pump light attenuating means is an optical fiber;

FIG. 9 is a schematic illustration of a reverse pumped fiber amplifier.

FIG. 10 is a schematic illustration of a dual ended device.

FIGS. 11, 12, and 13 and schematic illustrations of fiber amplifier embodiment in which the gain ion-doped signal filtering means is in series with the gain fiber.

FIG .14 is a schematic illustration of a fiber amplifier embodiment in which the gain ion-doped signal filtering means is distributed along the gain filter.

FIG. 15 is a graph illustrating the radial distribution of signal and pump power within the gain fiber of FIG. 14.

FIG. 16 is a schematic illustration of a fiber amplifier embodiment in which the gain ion-doped signal filtering means is contained within a fiber that extends along the gain fiber.

FIG. 17 is a graph illustrating the radial distribution of signal and pump power within coupler 83 of FIG. 16.

FIGS. 18 and 19 are schematic illustrations of fiber amplifier embodiment in which the absorbing ions of the signal filtering means are different from the gain ions.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fiber amplifiers typically include a gain fiber 10 (FIG. 1), the core of which is doped with gain ions that are capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p that is outside the predetermined band. A wavelength division multiplexer (WDM) fiber optic coupler 11 can be used for coupling pump energy of wavelength λ_p from laser diode 15 and the signal of wavelength λ_s from input telecommunication fiber 14 to gain fiber 10. Such devices are disclosed in U.S. Pat. Nos. 4,938,556, 4,941,726, 4,955,025 and 4,959,837. Fusion spheres are represented by large dots in the drawings. Input fiber 14 is spliced to coupler fiber 13, and gain fiber 10 is spliced to coupler fiber 12. Splice losses are minimized when coupler 11 is formed in accordance with the teachings of copending U.S. Patent Application Ser. No. 671,075 filed Mar. 18, 1991.

Various fiber fabrication techniques have been employed in the formation of rare earth-doped amplifying and absorbing optical fibers. A preferred process, which is described in copending U.S. Patent Application Ser. No. 07/715,348 filed June 14, 1991, is a modification of a process for forming standard telecommunication fiber preforms. In accordance with the teachings of that patent application, a porous core preform is immersed in a solution of a salt of the dopant dissolved in an organic solvent having no OH groups. The solvent is removed, and the porous glass preform is heat treated to consolidate it into a non-porous glassy body containing the dopant. The glassy body is provided with cladding glass to form a draw preform or blank that is drawn into an optical fiber. The process can be tailored so that it results in the formation of a fiber having the desired MFD. The porous core preform could consist soley of core glass, or it could consist of core glass to which some cladding glass has been added. By core glass is meant a relatively high refractive index glass, e.g. germania silicate glass, that will form the core of the resultant optical fiber.

If the rare earth ions are to extend to a region of the resultant fiber beyond the core, then the porous core preform that is immersed in dopant containing solvent must contain a central core glass region and a sufficiently thick layer of cladding glass. After the resultant doped, cladding-covered core preform has been consolidated, it is provided with additional cladding glass and drawn into a fiber.

If too much rare earth dopant is added to a GeO_2-doped silica core, the core can crystallize. Such higher rare earth dopant levels can be achieved without crystallization of the core glass by adding Al_2O_3 to the core.

As indicated above, it is sometimes desirable to modify the gain spectrum of a fiber amplifier. Since the erbium-doped fiber amplifier has utility in communication systems operating at 1550 nm, that fiber amplifier is specifically discussed herein by way of example. The invention also applies to fiber amplifiers containing gain ions other than erbium, since the gain spectrum of such other fiber amplifiers can also be advantageously modified. As shown by curve 23 of FIG. 2, the gain spectra of an erbium-aluminum-doped germania silicate fiber amplifier has peak around 1532 nm and a broad band with reduced gain to about 1560 nm. It is sometimes desirable to reduce the 1532 nm peak to prevent the

occurrence of such disadvantageous operation as wavelength dependent gain or gain (with concomitant noise) at unwanted wavelengths. Alternatively, it may be desirable to provide the fiber amplifier gain spectrum with a plurality of peaks so the amplifier can operate at a plurality of discrete wavelengths.

In accordance with the present invention, the amplifier spectral gain curve is altered by providing the fiber amplifier with filtering means 17 which includes absorbing ions that modify the gain spectrum by attenuating the amplified signal at various wavelengths in the gain spectrum. In accordance with a first aspect of the invention the absorbing ions are the same rare earth "gain ions" as the active gain ions in gain fiber 10; however, these absorbing gain ions must remain unpumped by light at wavelength λ_p. Such unpumped "gain ions" can be located in a fiber that is in series with gain fiber 10, or they can be distributed along the pumped gain fiber ions of gain fiber 10 but be located at a radius that is sufficiently greater than that of the pumped gain ions that they are substantially unpumped and yet influence the propagation of light of wavelength λ_s. This first aspect is further discussed in conjunction with FIGS. 2 through 17.

In accordance with a further aspect of the invention, the absorbing ions are different from the rare earth gain ions of gain fiber 10; such absorbing ions remain unexcited when subjected to light at wavelength λ_p. The absorbing ions can be positioned as follows: (a) they can be used to co-dope the gain fiber such that they are distributed along with the gain ions (optionally at the same radius as the gain ions), or (b) they can be incorporated into the core of a fiber that is connected in series with gain fiber 10. This further aspect is further discussed in conjunction with FIGS. 18 and 19.

In the figures discussed below, elements similar to those of FIG. 1 are represented by primed reference numerals.

FIG. 3 generally illustrates that embodiment wherein the absorbing ions are the same rare earth "gain ions" as the active dopant ions in the gain fiber. The fiber amplifier system includes unpumped gain ion filtering means 27 for altering the amplifier spectral gain curve. The unpumped gain ions can be located in series with the pumped gain fiber ions of gain fiber 10', or they can be distributed along the pumped gain fiber ions as discussed below in conjunction with FIGS. 14 and 15.

FIG. 4 shows that the unpumped gain ion filtering means can be located in series with the pumped gain fiber ions of fiber 10'. In the absence of an input signal at fiber 14', high levels of pump light can emanate from gain fiber 10'. Furthermore, some fiber amplifiers, especially those based on a three level laser system, are pumped at a power level that is sufficiently high that some remnant pump light emanates from the output end of gain fiber 10'. The presence of pump light along with the amplified signal at output end 30 of gain fiber 10' is indicated by the arrow labeled $\lambda_s+\lambda_p$. Means 31 substantially attenuates the remnant pump light, i.e. only an insignificant level of pump light, if any, remains. However, means 31 leaves the signal light at wavelength λ_s substantially unattenuated, i.e. it attenuates signal light less than about 0.5 dB. The arrow at the output of means 31 is therefore labelled λ_s. A length 32 of fiber doped with gain ions is spliced to the output end of attenuating means 31.

If fiber 10' of FIG. 4 has a germania silicate core doped with erbium and aluminum, for example, fiber 32

can also be doped with erbium or a combination of dopants including erbium. FIG. 5 shows the spectral transmission characteristic of an optical fiber having a germania silicate core doped with aluminum and unpumped erbium ions. The reduced transmission between about 1525 and 1560 nm is caused by the absorption of light at those wavelengths by erbium ions. The depression in transmission curve 34 at 1532 nm corresponds to the gain peak in curve 23 of FIG. 2. If fibers 10' and 32 of FIG. 4 are both co-doped with aluminum and erbium ions, the effect of absorbing fiber 32 will be to flatten the spectral gain curve of the resultant fiber amplifier (see curve 24 of FIG. 2).

If gain ion-doped fiber 32 of FIG. 4 had a germania silicate core doped with unpumped erbium ions, its absorption spectra would be represented by curve 35 of FIG. 6. If fiber 10' had the previously described core whereby its gain spectra was represented by curve 23 of FIG. 2, the net gain spectra of the resultant fiber amplifier would be that of FIG. 7. Such an amplifier can operate at three discrete wavelengths along curve 36 where peaks a, b and c are located.

The performance of the gain-ion doped filtering fiber may be improved by quenching the Er fluorescence to minimize signal induced bleaching of the absorption. The Er fluorescence can be quenched by adding dopants such as B or OH to the fiber or by increasing the doping density of Er in the absorbing fiber, for example, to levels above 500 ppm in SiO_2-GeO_2 fibers.

Attenuating means 31 of FIG. 4 could consist of a pump light reflector such as a fiber-type grating reflector of the type disclosed in the publication: K.O. Hill et al. "Photosensitivity in Optical Fiber Waveguides: Application to Reflection Filter Fabrication" Applied Physics Letters, vol. 32, pp. 647–649, (1978).

In the embodiment of FIG. 8, the pump light attenuating means is a fiber 38 that is spliced between gain fiber 10' and gain ion-doped fiber 32'. Fiber 38 must sufficiently attenuate light of wavelength λ_p that within a relatively short length, e.g. less than 20 m, the pump power at its output end 39 is attenuated to an insignificant level while signal light at wavelength λ_s is not unduly attenuated. Attenuating fiber 38 must be tailored to the specific gain fiber and pump wavelength. If the gain fiber 10' is an erbium-doped optical fiber that is pumped at a wavelength of 980 nm, fiber 38 can be doped with ytterbium, for example. Table 1 lists dopant candidates for use in pump light-absorbing fibers to be employed in conjunction with gain fibers doped with Er, Nd and Pr.

TABLE 1

Gain Ion	Wavelength Signal	Wavelength Pump	Absorbing Ion or Center
Er	1.52-1.6 μm	980 nm	Yb, Dy, Pr, V, CdSe
Er	1.52-1.6 μm	1480 nm	Pr, Sm
Er	1.52-1.6 μm	800 nm	Nd, Dy, Tm, V, CdSe
Nd	1.25-1.35 μm	800 nm	Dy, Er, Tm, V, CdSe
Pr	1.25-1.35 μm	1000 nm	Dy, Er, Yb, V,

Curves of absorptivity v. wavelength were used in selecting the rare earth ions and the transition metal (vanadium) ion. The CdSe should be present in the absorbing fiber in the form of micro crystallites.

The light attenuating fiber means of this invention is also useful in fiber amplifiers employing alternate pumping schemes. In the counter-pumping device of FIG. 9, wherein elements similar to those of FIG. 8 are represented by primed reference numerals, gain fiber 10' is

connected to input fiber 14' by attenuating fiber 38' and gain ion-doped fiber 32'. Pumping light of wavelength λ_p is coupled to gain fiber 10' by coupler 41 which also couples the amplified signal to output fiber 20'. Attenuating fiber 38' removes pump light that would have excited the gain ions in fiber 32'. Since the gain ions in fiber 32' remain unexcited by pump light, fiber 32' filters the incoming signal.

In the dual-ended device of FIG. 10, coupler 43 couples the signal from input telecommunication fiber 45 and pumping power from first pump source 44 to gain fiber section 46*a*, as described in conjunction with FIG. 4. Coupler 47 couples pumping power from second pump source 48 to gain fiber section 46*b*. The output signal of wavelength λ_s is coupled by coupler 47 from gain fiber section 46*b* to outgoing telecommunication fiber 50. Pump light attenuating fibers 52*a* and 52*b* are spliced to gain fiber sections 46*a* and 46*b*. A length 53 of fiber doped with gain ions is spliced between attenuating fiber sections 52*a* and 52*b*. In the absence of the attenuating fiber sections, remnant pump light from sources 44 and 48 would be coupled from the gain fiber sections 46*a* and 46*b*, respectively, to gain ion-doped fiber 53, thereby negating its filtering ability. Since the characteristics of fiber 53 are similar to those of fiber 32' of FIG. 8, the fiber amplifier is provided with a modified spectral gain.

The signal is first introduced into section 46*a* where it gradually increases in amplitude due to amplification in that section. The amplitude of the original that is introduced into section 46*b* is therefore much greater that that which was introduced into section 46*a*. The pump power is therefore absorbed at a greater rate per unit length in section 46*b*, and section 46*b* can be shorter than section 46*a*.

In the embodiment of FIG. 11 the length of gain fiber 57 is sufficient to dissipate all of the pump light from source 15' so that essentially no pump light reaches end 58 thereof. Gain ion-doped fiber 32' can therefore filter the amplified signal. However, for lowest noise amplification, an adequate pump light intensity should exist throughout the amplifier medium. The amplifier of FIG. 11 therefore generates more noise than previously described embodiments.

Gain fiber 62 of FIG. 12 can be provided with pump power from either or both of the couplers 60 and 61. This embodiment pertains to forward pumped, reverse pumped and double pumped fiber amplifiers. In the reverse pumped embodiment, coupler 60 is unnecessary. In all cases, the signal is amplified by gain fiber 62 and coupled to outgoing telecommunication fiber by coupler 61. In the reverse pumping mode, pump light propagates from coupler 61 into end 65 of gain fiber 62. In the forward and double pump situations, only a small fraction of the remnant pump light exiting output end 65 of fiber 62 is coupled to coupler fiber 66. Since gain ion-doped fiber 64 remains essentially unpumped, it filters the amplified signal light that is coupled to outgoing telecommunication fiber 63.

FIG. 13 shows a simplified embodiment wherein filtering fiber 74 contains a dopant that absorbs pump light; it also contains gain ions for altering the amplifier spectral gain curve. The concentration of the pump light attenuating ions is such that their absorption is much greater than that of the gain ions in fiber 74. For example, the absorption of pump light might be ten times the absorption of signal light. Thus, the remnant

pump light is absorbed within a short distance of the input end 75 of fiber 74. The remainder of fiber 74 filters the amplified signal from fiber 10'.

In the embodiment of FIG. 14, gain fiber 79 itself is designed such that it contains dopant ions at a sufficiently large radius that only the relatively large mode field of the signal light reaches the large radii dopant ions. As shown in FIG. 15, the signal field extends to a greater radius in gain fiber 79 than the pump field. If the signal field extends to radius r_2, the erbium ions, for example, should also extend to a radius of about r_2. Since Er ions having radii larger than about r_1 remain umpumped, those large radii Er ions are available for filtering the signal.

The embodiment of FIG. 16 employs a fiber optic coupler-type device 83 that is formed by fusing together a gain fiber 81 and a gain ion doped signal attenuating fiber 82. Device 83 can be similar to the overclad coupler of the type disclosed in U.S. Pat. No. 4,931,076 or the fused fiber coupler of the type disclosed in T. Bricheno et al. "Stable Low-Loss Single-Mode Couplers" Electronics Letters, vol. 20, pp. 230-232 (1984). Pump light and signal are coupled to gain fiber 81 from input coupler fiber 12'. The fibers 81 and 82 of coupler 83 have sufficiently different propagation constants that, because of the resultant $\Delta\beta$, no coupling occurs. However, the large radius signal field from gain fiber 81 significantly overlaps the absorbing region of fiber 82 in that portion of the coupler where fibers 81 and 82 are fused together and stretched to decrease the distance between cores. Since there is a negligible overlap of the smaller radius pump field into the gain ion-doped region of fiber 82 (see FIG. 17), the gain ions remain unexcited and can filter the signal light.

That aspect of the invention wherein the signal absorbing ions are different from the rare earth gain ions of the gain fiber is illustrated in FIGS. 18 and 19. The fiber amplifier of FIG. 18 includes gain fiber 90, the core of which is doped with gain ions that are capable of producing stimulated emission of light within a band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p. The signal and pump light are coupled to gain fiber 90 via coupler fiber 12'. Gain fiber 90 is co-doped with absorbing ions that are different from the gain ions; therefore, the pump light attenuating means of the previous embodiments can be eliminated. Table 2 lists dopant candidates for use as absorbing ions to be employed in conjunction with gain fibers in which Er, Nd and Pr are the gain ions.

TABLE 2

Gain Ion	Gain Wavelength Range	Absorbing Ion
Er	1.52-1.61 μm	Pr, Sm
Nd	1.25-1.35 μm (undesired gain at 1060 nm)	Sm, Dy, Pr
Pr	1.25-1.35 μm	Sm, Dy, Nd

Curves of absorptivity v. wavelength were used in selecting the absorbing ions of Table 2.

During the fabrication of a preform for drawing a gain fiber that is co-doped with absorbing ions as well as active gain ions, the central region of the fiber is provided with a sufficient concentration of active gain ions to provide the desired amplification; it is also provided with a sufficient concentration of absorbing ions to attenuate the undesired portion or modify the gain spectrum. Such a fiber could be formed in accordance with

the aforementioned U.S. Pat. Application Ser. No. 07/715,348 by immersing the porous core preform in a dopant solution containing salts of both the active dopant ion and the absorbing ion.

That embodiment wherein the absorbing ions are incorporated into the core of a fiber that is connected in series with gain fiber is shown in FIG. 19 wherein absorbing fiber 93 is spliced between two sections 92a and 92b of gain fiber. Alternatively, the absorbing fiber could be spliced to the output end or input end of a single section of gain fiber.

I claim:

1. A fiber amplifier comprising

a gain optical fiber having a single-mode core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, said gain fiber having input and output ends,

absorbing ion filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said absorbing ion filtering means comprising umpumped gain ions,

means for introducing a signal of wavelength λ_s into said gain fiber input end,

means introducing pump light of wavelength λ_p into said gain fiber, and

means for preventing the excitation of said pumped gain ions by light of wavelength λ_p.

2. A fiber amplifier in accordance with claim 1 wherein said umpumped gain ions are situated in a signal filtering optical fiber that is connected in series with said gain fiber.

3. A fiber amplifier in accordance with claim 2 wherein said means for preventing excitation is connected in series between said gain fiber and said filtering optical fiber.

4. A fiber amplifier in accordance with claim 3 wherein said means for preventing excitation comprises a fiber-type grating reflector for reflecting pump light.

5. A fiber amplifier in accordance with claim 3 wherein said means for preventing excitation comprises interference filter means for removing pump light.

6. A fiber amplifier in accordance with claim 3 wherein said means for preventing excitation comprises an optical fiber containing a dopant that substantially attenuates light at wavelength λ_p.

7. A fiber amplifier in accordance with claim 6 wherein said pump light attenuating optical fiber connects said signal attenuating fiber to the input end of said gain fiber.

8. A fiber amplifier in accordance with claim 6 wherein said gain fiber comprises first and second sections, and said pump light attenuating fiber comprises first and second sections, said fiber amplifier comprises the serially connected arrangement of the first section of said gain fiber, said first section of said pump light attenuating fiber, said gain ion-doped pump light attenuating fiber, the second section of said pump light attenuating fiber and the second section of said gain fiber, said means for introducing pump light comprising means for introducing pump light into said first and second gain fiber sections.

9. A fiber amplifier in accordance with claim 3 wherein means for preventing excitation comprises an optical fiber coupler which couples essentially no pump light from said gain fiber to said signal attenuating fiber.

10. A fiber amplifier in accordance with claim 1 wherein said means preventing excitation of umpumped gain ions by pump light comprises a sufficient length of gain fiber to dissipate all of the pump light introduced therein.

11. A fiber amplifier in accordance with claim 1 wherein said absorbing ion filtering means comprises an optical fiber containing unpumped gain ions and a dopant for absorbing pump light, the concentration of said dopant being much greater than unpumped gain ions.

12. A fiber amplifier in accordance with claim 1 wherein the radial distribution of said gain ions in said gain fiber extends beyond the mode field radius of light of wavelength λ_p, whereby those gain ions at radii greater than said mo field radius are unexcited by pump light and are free to absorb signal light.

13. A fiber amplifier in accordance with claim 1 wherein a section of said gain fiber is fused in side-by-side arrangement to a further section of optical fiber doped with gain ions to form a fused region into which signal light but not pump light can extend from said gain fiber into said further section, whereby those gain ions of said further section are unexcited by pump light and are free to absorb signal light.

14. A fiber amplifier in accordance with claim 1 said gain fiber is in series with an optical fiber containing signal light absorbing ions that are different from said gain ions.

15. A fiber amplifier comprising

a gain optical fiber having a single-mode core containing gain ions capable of producing stimulated emission of signal light within a predetermined band of wavelengths including a wavelength λ_s when pumped with pump light of wavelength λ_p, said gain fiber having first and second ends,

a filtering fiber containing gain ions for filtering signal light,

a pump light-attenuating fiber having a core containing a dopant that attenuates said pump light while signal light remains substantially unattenuated, said pump light-attenuating fiber connecting the second end of said gain fiber to an end of said filtering fiber,

means for introducing pump light of wavelength λ_p into the first end of said said gain fiber, and

means for introducing a signal of wavelength λ_s into one of the ends of the series combination of said gain fiber, said pump light-attenuating fiber and said filtering fiber, the gain ions of said filtering fiber remaining unexcited during operation because of the pump light filtering action of said pump light-attenuating fiber, whereby said filtering fiber alters the spectral gain of said amplifier.

16. A fiber amplifier comprising

first and second gain optical fiber sections, each having a single-mode core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, each gain fiber section having first and second ends,

first and second pump light-attenuating fiber sections, each having a core containing a dopant that attenuates optical power in at least one wavelength band

including said wavelength λ_p, while optical power at said wavelength λ_s remains substantially unattenuated thereby, each pump light-attenuating fiber section having first and second ends, the first end of each of said pump light-attenuating fiber sections being spliced to a respective one of the second ends of said gain fiber sections,

a filtering fiber, the ends of which are respectively connected to the second ends of said pump light attenuating fiber sections, said filtering fiber being doped with gain ions,

means for introducing pump light of wavelength λ_p into the first end of each of said gain fiber sections, and

means for introducing a signal of wavelength λ_s into the first end of one of said gain fiber sections, the gain ions of said filtering fiber remaining unexcited during operation because of the pump light filtering action of said pump light-attenuating fiber.

17. A fiber amplifier comprising

a gain optical fiber having a single-mode core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, said gain fiber having input and output ends,

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing ions that can be excited by light of wavelength λ_p,

means for introducing a signal of wavelength λ_s into said gain fiber input end,

means introducing pump light of wavelength λ_p into said gain fiber, and

means for preventing the excitation of said filtering means by light of wavelength λ_p.

18. A fiber amplifier in accordance with claim 17 wherein said gain fiber is co-doped with signal light absorbing ions that are different from said gain ions.

19. A fiber amplifier comprising

a gain optical fiber having a single-mode core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_s when pumped with light of wavelength λ_p, said gain fiber having input and output ends, said dopant ions being selected from the group consisting of erbium, neodymium and praseodymium,

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing a dopant selected from the group consisting of erbium, dysprosium, neodymium, ytterbium, samarium, praseodymium, thulium, vanadium and cadmium selenide,

means for introducing a signal of wavelength λ_s into said gain fiber input end, and

means introducing pump light of wavelength λ_p into said gain fiber.

20. A gain amplifier in accordance with claim 19 wherein said filtering means comprises an optical fiber containing said dopant ions.

* * * * *

DOCKET No. CORN 0002 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re reissue patent application of:

Hall et al.

U.S. Patent No. 5,131,069 Issued July 14, 1992

Serial No.: 07/743,726 Group No.: 2501

Filed: August 12, 1991 Examiner: S. Barns

For: **FIBER AMPLIFIER HAVING MODIFIED GAIN SPECTRUM**

Assistant Commissioner for Patents
Washington, DC 20231

Sir:

PRELIMINARY AMENDMENT OF REISSUE APPLICATION

Please amend the above-identified reissue application as follows:

Add the following claims:

-- 21. A fiber amplifier comprising

a gain optical fiber having only one single-mode core, said core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, said gain fiber having input and output ends,

absorbing ion filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said absorbing ion filtering means comprising umpumped gain ions,

means for introducing a signal of wavelength λ_S into said gain fiber input end,

means introducing pump light of wavelength λ_P into said gain fiber, and

means for preventing the excitation of said pumped gain ions by light of wavelength λ_P.

22. A fiber amplifier in accordance with claim 21 wherein said umpumped gain ions are situated in a signal filtering optical fiber that is connected in series with said gain fiber.

23. A fiber amplifier in accordance with claim 22 wherein said means for preventing excitation is connected in series between said gain fiber and said filtering optical fiber.

24. A fiber amplifier in accordance with claim 23 wherein said means for preventing excitation comprises a fiber-type grating reflector for reflecting pump light.

25. A fiber amplifier in accordance with claim 23 wherein said means for preventing excitation comprises interference filter means for removing pump light.

26. A fiber amplifier in accordance with claim 23

wherein said means for preventing excitation comprises an optical fiber containing a dopant that substantially attenuates light at wavelength λ_p.

27. A fiber amplifier in accordance with claim 26 wherein said pump light attenuating optical fiber connects said signal attenuating fiber to the input end of said gain fiber.

28. A fiber amplifier in accordance with claim 26 wherein said gain fiber comprises first and second sections, and said pump light attenuating fiber comprises first and second sections, said fiber amplifier comprises the serially connected arrangement of the first section of said gain fiber, said first section of said pump light attenuating fiber, said gain ion-doped pump light attenuating fiber, the second section of said pump light attenuating fiber and the second section of said gain fiber, said means for introducing pump light comprising means for introducing pump light into said first and second gain fiber sections.

29. A fiber amplifier in accordance with claim 23 wherein means for preventing excitation comprises an optical fiber coupler which couples essentially no pump light from said gain fiber to said signal attenuating fiber.

30. A fiber amplifier in accordance with claim 21 wherein said means preventing excitation of umpumped gain ions by pump light comprises a sufficient length of gain fiber to dissipate all of the pump light introduced therein.

31. A fiber amplifier in accordance with claim 21 wherein said absorbing ion filtering means comprises an optical fiber containing unpumped gain ions and a dopant for absorbing pump light, the concentration of said dopant being much greater than unpumped gain ions.

32. A fiber amplifier in accordance with claim 21 wherein the radial distribution of said gain ions in said gain fiber extends beyond the mode field radius of light of wavelength λ_p, whereby those gain ions at radii greater than said mo field radius are unexcited by pump light and are free to absorb signal light.

33. A fiber amplifier in accordance with claim 21 wherein a section of said gain fiber is fused in side-by-side arrangement to a further section of optical fiber doped with gain ions to form a fused region into which signal light but not pump light can extend from said gain fiber into said further section, whereby those gain ions of said further section are unexcited by pump light and are free to absorb signal light.

34. A fiber amplifier in accordance with claim 21 said gain fiber is in series with an optical fiber containing signal light absorbing ions that are different from said gain ions.

35. A fiber amplifier comprising

a gain optical fiber having only one single-mode core, said core containing gain ions capable of producing stimulated emission of signal light within a predetermined band of wavelengths including a wavelength λ_S when pumped with pump light of wavelength λ_P, said gain fiber having first and second ends,

a filtering fiber containing gain ions for filtering signal light,

a pump light-attenuating fiber having a core containing a dopant that attenuates said pump light while signal light remains substantially unattenuated, said pump light-attenuating fiber connecting the second end of said gain fiber to an end of said filtering fiber,

means for introducing pump light of wavelength λ_P into the first end of said said gain fiber,

and means for introducing a signal of wavelength λ_S into one of the ends of the series combination of said gain fiber, said pump light-attenuating fiber and said filtering fiber, the gain ions of said filtering fiber remaining unexcited during operation because of the pump light filtering action of said pump light-attenuating fiber, whereby said filtering fiber

alters the spectral gain of said amplifier.

36. A fiber amplifier comprising

first and second gain optical fiber sections, each having only one single-mode core, said core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, each gain fiber section having first and second ends,

first and second pump light-attenuating fiber sections, each having a core containing a dopant that attenuates optical power in at least one wavelength band including said wavelength λ_P, while optical power at said wavelength λ_S remains substantially unattenuated thereby, each pump light-attenuating fiber section having first and second ends, the first end of each of said pump light-attenuating fiber sections being spliced to a respective one of the second ends of said gain fiber sections,

a filtering fiber, the ends of which are respectively connected to the second ends of said pump light attenuating fiber sections, said filtering fiber being doped with gain ions,

means for introducing pump light of wavelength λ_P into the first end of each of said gain fiber sections, and

means for introducing a signal of wavelength λ_S into the first end of one of said gain fiber sections, the gain ions of said filtering fiber remaining unexcited during operation

because of the pump light filtering action of said pump light-attenuating fiber.

37. A fiber amplifier comprising

a gain optical fiber having only one single-mode core, said core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, said gain fiber having input and output ends,

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing ions that can be excited by light of wavelength λ_P,

means for introducing a signal of wavelength λ_S into said gain fiber input end,

means introducing pump light of wavelength λ_P into said gain fiber, and

means for preventing the excitation of said filtering means by light of wavelength λ_P.

38. A fiber amplifier in accordance with claim 37 wherein said gain fiber is co-doped with signal light absorbing ions that are different from said gain ions.

39. A fiber amplifier comprising

a gain optical fiber having only one single-mode core, said core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, said gain fiber having input and output ends, said dopant ions being selected from the group consisting of erbium, neodymium and praseodymium,

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing a dopant selected from the group consisting of erbium, dysprosium, neodymium, ytterbium, samarium, praseodymium, thulium, vanadium and cadmium selenide,

means for introducing a signal of wavelength λ_S into said gain fiber input end, and

means introducing pump light of wavelength λ_P into said gain fiber.

40. A gain amplifier in accordance with claim 39 wherein said filtering means comprises an optical fiber containing said dopant ions.

41. A fiber amplifier having a flattened gain spectrum comprising

a gain optical fiber having only one single-mode core, said core containing dopant ions capable of producing a gain

spectrum due to stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, said gain fiber having input and output ends, and wherein the gain spectrum of said gain optical fiber over said band of wavelengths has a first portion having a relatively small gain variation over a region of said band wavelengths and a second portion having a relatively large gain variation over a different region of said band wavelengths, wherein said first portion of the gain spectrum is relatively flat and wherein said second portion is not flat and exhibits a greater gain than the gain exhibited over said relatively flat portion;

ion filtering means for absorbing light within said predetermined band of wavelengths, said ion filtering means having an absorption spectrum having a first portion exhibiting relatively small absorption over said region of said band of wavelengths and a second portion having a relatively large absorption of said different region of said band of wavelengths where the gain spectrum is not flat, said ion filtering means comprising a concentration and distribution of umpumped gain ions within said ion filtering means wherein amplified light having wavelengths within said predetermined band of wavelengths where the gain spectrum is not flat is attenuated to an extent such that the gain spectrum over the entire predetermined band of wavelengths is flattened and exhibits relatively small gain

variation over said entire band of wavelengths;

means for introducing a signal of wavelength λ_S into said gain fiber input end,

means introducing pump light of wavelength λ_P into said gain fiber, and

means for preventing the excitation of said pumped gain ions by light of wavelength λ_P.

42. A fiber amplifier comprising

a gain optical fiber having only one single-mode core, said core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, said gain fiber having input and output ends, and wherein the gain spectrum of said gain optical fiber, over said band of wavelengths and when pumped with light from wavelength λ_P has a first portion which is relatively flat and a second portion which is not flat and exhibits gain greater than the gain exhibited over said relatively flat portion;

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing ions that can be excited by light of wavelength λ_P, said filtering means having a transmission curve over said predetermined band of wavelengths

and in the absence of excitation by said gain fiber over said predetermined band of wavelengths when said gain fiber is excited by light at wavelength λ_P so that when light in the range of said predetermined range of wavelengths is amplified and filtered by said filtering means, the resulting gain spectrum for said amplifier over said predetermined range of wavelengths is substantially flat;

means for introducing a signal of wavelength λ_S into said gain fiber input end,

means introducing pump light of wavelength λ_P into said gain fiber, and

means for preventing the excitation of said filtering means by light of wavelength λ_P.

43. A fiber amplifier comprising

a gain optical fiber having only one single-mode core, said core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, said gain fiber having input and output ends, said dopant ions being selected from the group consisting of erbium, neodymium and praseodymium, and wherein the gain spectrum of said gain optical fiber, over said band of wavelengths and when pumped with light from wavelength λ_P has a first portion which is relatively flat and a second portion which is not flat and

exhibits gain greater than the gain exhibited over said relatively flat portion;

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing a dopant selected from the group consisting of erbium, dysprosium, neodymium, ytterbium, samarium, praseodymium, thulium, vanadium and cadmium selenide, said filtering means having a transmission curve over said predetermined band of wavelengths and in the absence of excitation by said gain fiber over said predetermined band of wavelengths when said gain fiber is excited by light at wavelength λ_P so that when light in the range of said predetermined range of wavelengths is amplified and filtered by said filtering means, the resulting gain spectrum for said amplifier over said predetermined range of wavelengths is substantially flat;

means for introducing a signal of wavelength λ_S into said gain fiber input end, and

means introducing pump light of wavelength λ_P into said gain fiber.

44. An optical fiber amplifier having a flattened gain spectrum for use over a wavelength range of about 1530 to about 1560nm comprising:

a gain optical fiber having only one core, said core

containing ions capable of producing stimulated emission of light within the band of wavelengths extending from about 1530 to about 1560nm when pumped with light having a wavelength capable of causing said stimulated emission in said band of wavelengths, said stimulated emission from said gain fiber exhibiting a gain spectrum including a peak around 1532nm and a substantially flat gain region extending from about 15460nm to about 1560nm, said gain fiber having input and output ends;

a gain spectrum fiber exhibiting an absorption spectrum and having an input end and an output end, one of the input and output ends of said filtering fiber being optically connected to one of the output and input ends, respectively, of said gain fiber, said filtering fiber having a core doped with ions which are capable of absorbing light according to said absorption spectrum within the band of wavelengths extending from about 1530 to about 1560nm, the absorption spectrum of said filtering fiber having a substantially non-flat absorption spectrum in the spectral region from about 1530 to about 1540nm and particularly at about 1532nm and having a relatively flat absorption spectrum in the region from about 1540 to about 1560nm, the absorption spectrum exhibiting a lower absorption in the region from about 1540 to about 1560nm than the absorption in the spectral region from about 1530 to about 1540nm and particularly at about 1532nm, one of the input and output ends of said filtering fiber being adapted for connection to a transmission fiber input end;

means for introducing pump light into at least one of the input and output ends of said gain fiber; and

means for introducing a light signal having a wavelength in the range from about 1530 to about 1560nm into the input end of said gain fiber wherein said pump light stimulated emission in said gain fiber over the wavelength range from about 1530 to about 1560nm and an amplified signal in the range from about 1530 to about 1540nm is not attenuated below a level about equal to the magnitude of an amplified signal in the wavelength range from about 1540 to about 1560nm.

45. The amplifier of claim 44 wherein said means for introducing pump light comprises at least two pump sources.

46. The amplifier of claim 44 wherein said amplifier is reverse pumped.

47. The amplifier of claim 44 which further comprises means between said gain fiber and said filtering fiber for filtering light in the pump wavelength spectrum.

48. The amplifier of claim 44 wherein the pump light has a wavelength centered around at least one of about 980nm and 1480nm.

49. The amplifier of claim 45 wherein the at least two pump sources have a wavelength centered around at least one of about 980nm and 1480nm.

50. The amplifier of claim 45 further comprising at least a second gain optical fiber consisting of one core which contains ions capable of producing stimulated emission of light within the band of wavelengths extending from about 1530 to about 1560nm when pumped with light having a wavelength capable of causing said stimulated emission in said band of wavelengths, said stimulated emission from said gain fiber exhibiting a gain spectrum including a peak around 1532nm and a substantially flat gain region extending from about 1540nm to about 1560nm, said second gain fiber having input and output ends; wherein said at least first and second gain fibers and said filtering fiber are optically interconnected in a series arrangement.

REMARKS

Reissue Claims

Newly added independent claims 21-40 correspond exactly to original claims 1-20, except that the "gain optical fiber" is now limited to a fiber "having only one single-mode core" as contrasted to the original claim limitation "having a single-mode core." It was noted that the original claim limitation could have raised a question as to whether claims 1-20 were limited to

a structure having only one core.

To obviate any questions, patentees have elected to enter claims 21-40 herein that are the same as claims 1-20, respectively, but are limited to a structure having only one core. Such a structure is clearly set forth in the original patent specification and drawings, e.g., see Figs. 1, 4, 10 and 11 and at column 3, line 38, and at column 4, line 67, for example. No new matter is being added and the scope of the claims is not expanded beyond the scope of original claims 1-20.

New claims 41-44 are modifications of original patent claims 1, 17, 19 and 21, respectively. The modifications can best be seen in Appendix A to this paper wherein the words deleted from those original claims are in brackets and the added words are in bold face type. Support for the added matter appears in the footnotes to those claims in Appendix A.

Claims 45-50 are basically new and support for the added matter appears in the footnotes to those claims in Appendix A.

As can be seen, applicants have not added new matter to the added claims and have not expanded the scope of any beyond the scope of the original patent claims 1-20.

Interference No. 104,069

An interference was declared between the applicants Hall et al. original patent and a reissue application of Grasso et al., U.S. Patent No. 5,087,108, a copy of which patent is

enclosed herewith. In that interference, the Hall '069 patent claims 1-2, 10, 12-14 and 17-20 were designated as corresponding to the counts of that interference.

As can be seen in the Grasso '108 patent, the invention thereof is in an optical fiber amplifier having a "double core" fiber. Indeed, in the specification at column 9, lines 30-40, and column 10, lines 56-66, Grasso states that an amplifier made by Grasso from a "single-core" fiber was "practically useless." Such a disclosure clearly teaches away from making an amplifier from a single core fiber and would not in any way teach or suggest applicants' successful construction of a single-core amplifier.

Applicants claims 21-50 are clearly patentable over the art of record and the Grasso patent and an allowance of such claims is earnestly solicited.

Respectfully submitted,

Francis A. Paintin

Francis A. Paintin
Registration No. 19,386

Date: June 26, 1998

WOODCOCK WASHBURN KURTZ
MACKIEWICZ & NORRIS LLP
One Liberty Place - 46th Floor
Philadelphia, PA 19103
(215) 568-3100

APPENDIX A

Clarification of Claims 41-50

[1] **41.** A fiber amplifier **having a flattened gain spectrum**[1] comprising

a gain optical fiber having [a] **only one** single-mode core, **said core** containing dopant ions capable of producing **a gain spectrum due to** stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, said gain fiber having input and output ends, **and wherein the gain spectrum of said gain optical fiber over said band of wavelengths has a first portion having a relatively small gain variation over a region of said band wavelengths and a second portion having a relatively large gain variation over a different region of said band wavelengths, wherein said first portion of the gain spectrum is relatively flat and wherein said second portion is not flat and exhibits and exhibits a greater gain than the gain exhibited over said relatively flat portion**[2];

[absorbing]**ion filtering** means for [attenuating]

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[1] Col. 1, lines 20, 65-68.

[2] Col. 3, lines 64-67, and Figs. 2, 5-7.

absorbing light within said predetermined band of wavelengths, said [absorbing] ion filtering means **having an absorption spectrum having a first portion exhibiting relatively small absorption over said region of said band of wavelengths and a second portion having a relatively large absorption of said different region of said band of wavelengths where the gain spectrum is not flat, said ion filtering means comprising a concentration and distribution of umpumped gain ions within said ion filtering means wherein amplified light having wavelengths within said predetermined band of wavelengths where the gain spectrum is not flat is attenuated to an extent such that the gain spectrum over the entire predetermined band of wavelengths is flattened and exhibits relatively small gain variation over said entire band of wavelengths**[3];

means for introducing a signal of wavelength λ_S into said gain fiber input end,

means introducing pump light of wavelength λ_P into said gain fiber, and

means for preventing the excitation of said pumped gain ions by light of wavelength λ_P.

[17] **42.** A fiber amplifier comprising

a gain optical fiber having [a] **only one** single-mode

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[3] Col.4, lines 16-48; col. 5, lines 2-17; col. 6, line 61, and col. 7, line 14; and Figs5-6.

core, said core containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, said gain fiber having input and output ends, and wherein the gain spectrum of said gain optical fiber, over said band of wavelengths and when pumped with light from wavelength λ_P has a first portion which is relatively flat and a second portion which is not flat and exhibits gain greater than the gain exhibited over said relatively flat portion[4];

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing ions that can be excited by light of wavelength λ_P, said filtering means having a transmission curve over said predetermined band of wavelengths and in the absence of excitation by said gain fiber over said predetermined band of wavelengths when said gain fiber is excited by light at wavelength λ_P so that when light in the range of said predetermined range of wavelengths is amplified and filtered by said filtering means, the resulting gain spectrum for said amplifier over said predetermined range of wavelengths is substantially flat[5];

means for introducing a signal of wavelength λ_S into

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[4] See footnote 2.

[5] See footnote 3.

said gain fiber input end,

means introducing pump light of wavelength λ_P into said gain fiber, and

means for preventing the excitation of said filtering means by light of wavelength λ_P.

[19] **43.** A fiber amplifier comprising

a gain optical fiber having [a] **only one** single-mode core, **said core** containing dopant ions capable of producing stimulated emission of light within a predetermined band of wavelengths including a wavelength λ_S when pumped with light of wavelength λ_P, said gain fiber having input and output ends, said dopant ions being selected from the group consisting of erbium, neodymium and praseodymium, **and wherein the gain spectrum of said gain optical fiber, over said band of wavelengths and when pumped with light from wavelength λ_P has a first portion which is relatively flat and a second portion which is not flat and exhibits gain greater than the gain exhibited over said relatively flat portion**[6];

filtering means for attenuating light at at least some of the wavelengths within said predetermined band of wavelengths, said filtering means containing a dopant selected from the group consisting of erbium, dysprosium, neodymium, ytterbium, samarium,

[6] See footnote 2.

praseodymium, thulium, vanadium and cadmium selenide, said filtering means having a transmission curve over said predetermined band of wavelengths and in the absence of excitation by said gain fiber over said predetermined band of wavelengths when said gain fiber is excited by light at wavelength λ_P so that when light in the range of said predetermined range of wavelengths is amplified and filtered by said filtering means, the resulting gain spectrum for said amplifier over said predetermined range of wavelengths is substantially flat[7];

means for introducing a signal of wavelength λ_S into said gain fiber input end, and

means introducing pump light of wavelength λ_P into said gain fiber.

<u>New Claims 44-50</u>

44. An optical fiber amplifier having a flattened gain spectrum for use over a wavelength range of about 1530 to about 1560nm comprising:

a gain optical fiber consisting of one core, said containing ions capable of producing stimulated emission of light within the band of wavelengths extending from about 1530 to about

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[7] See footnote 3.

1560nm when pumped with light having a wavelength capable of causing said stimulated emission in said band of wavelengths, said stimulated emission from said gain fiber exhibiting a gain spectrum including a peak around 1532nm and a substantially flat gain region extending from about 15460nm to about 1560nm, said gain fiber having input and output ends;

a gain spectrum fiber exhibiting an absorption spectrum and having an input end and an output end, one of the input and output ends of said filtering fiber being optically connected to one of the output and input ends, respectively, of said gain fiber, said filtering fiber having a core doped with ions which are capable of absorbing light according to said absorption spectrum within the band of wavelengths extending from about 1530 to about 1560nm, the absorption spectrum of said filtering fiber having a substantially non-flat absorption spectrum in the spectral region from about 1530 to about 1540nm and particularly at about 1532nm and having a relatively flat absorption spectrum in the region from about 1540 to about 1560nm, the absorption spectrum exhibiting a lower absorption in the region from about 1540 to about 1560nm than the absorption in the spectral region from about 1530 to about 1540nm and particularly at about 1532nm, one of the input and output ends of said filtering fiber being adapted for connection to a transmission fiber input end;

means for introducing pump light into at least one of the input and output ends of said gain fiber; and

means for introducing a light signal having a wavelength in the range from about 1530 to about 1560nm into the input end of said gain fiber wherein said pump light stimulated emission in said gain fiber over the wavelength range from about 1530 to about 1560nm and an amplified signal in the range from about 1530 to about 1540nm is not attenuated below a level about equal to the magnitude of an amplified signal in the wavelength range from about 1540 to about 1560nm[8].

45. The amplifier of claim 44 wherein said means for introducing pump light comprises at least two pump sources[9].

46. The amplifier of claim 44 wherein said amplifier is reverse pumped[10].

47. The amplifier of claim 44 which further comprises means between said gain fiber and said filtering fiber for filtering light in the pump wavelength spectrum[11].

48. The amplifier of claim 44 wherein the pump

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[8] Col. 1, lines 1-9; col. 3, lines 66-68; col. 4, lines 17-49; col. 5 lines 2-16 and line 66, to col. 6, line 8; col. 7, lines 59-60; and Figs. 1, 4, 10-12.

[9] Col. 6, lines 48-60.

[10] See footnote 9.

[11] Col. 4, lines 48-66; col. 5, line 29, to col. 6, line 8.

light has a wavelength centered around at least one of about 980nm and 1480nm[12].

49. The amplifier of claim 45 wherein the at least two pump sources have a wavelength centered around at least one of about 980nm and 1480nm[13].

50. The amplifier of claim 45 further comprising at least a second gain optical fiber consisting of one core which contains ions capable of producing stimulated emission of light within the band of wavelengths extending from about 1530 to about 1560nm when pumped with light having a wavelength capable of causing said stimulated emission in said band of wavelengths, said stimulated emission from said gain fiber exhibiting a gain spectrum including a peak around 1532nm and a substantially flat gain region extending from about 1540nm to about 1560nm, said second gain fiber having input and output ends; wherein said at least first and second gain fibers and said filtering fiber are optically interconnected in a series arrangement[14].

[12] Col. 5, lines 44-45, and Table 1.

[13] See footnote 12 and col. 5, line 64, to col. 6, line 60.

[14] Col. 6, lines 9-36, and Fig. 10.

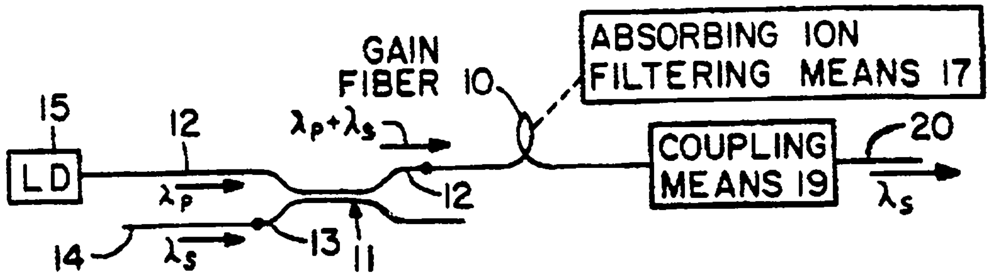


Fig. 1

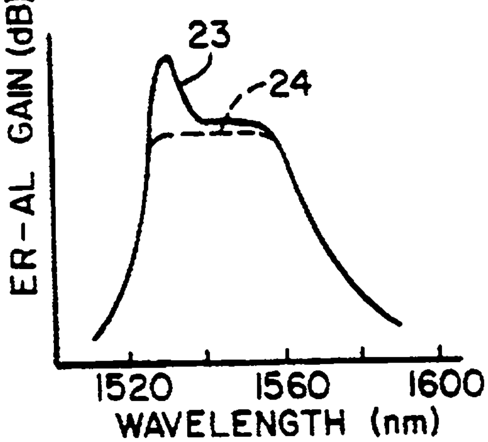


Fig. 2

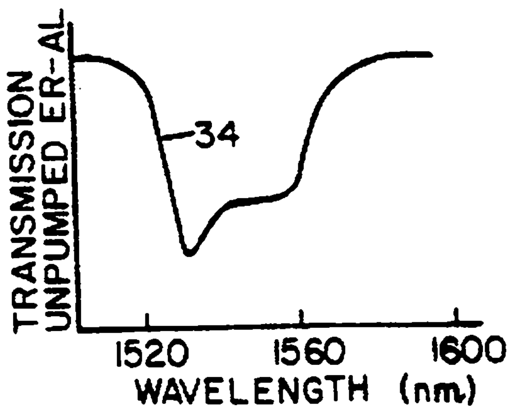


Fig. 5

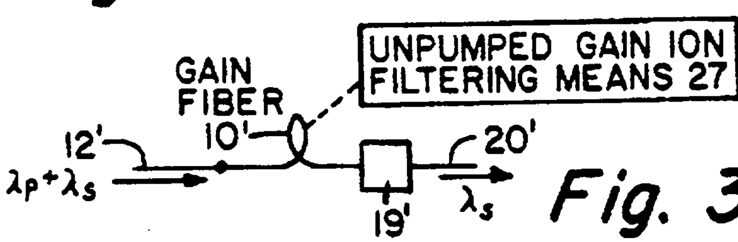


Fig. 3

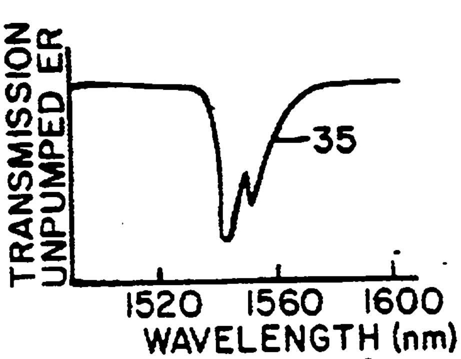


Fig. 6

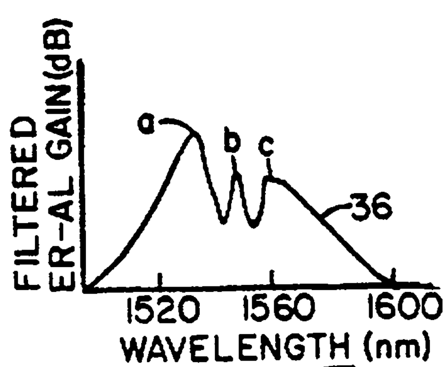


Fig. 7

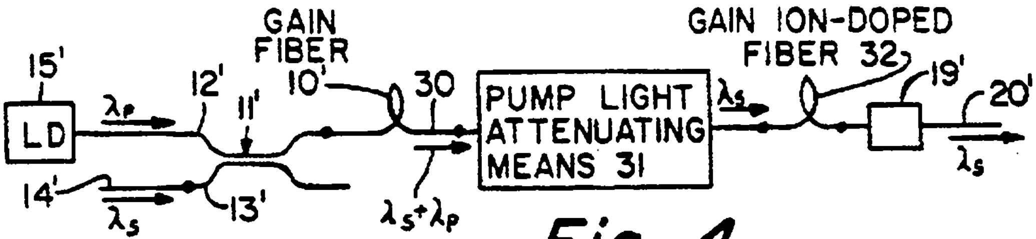


Fig. 4

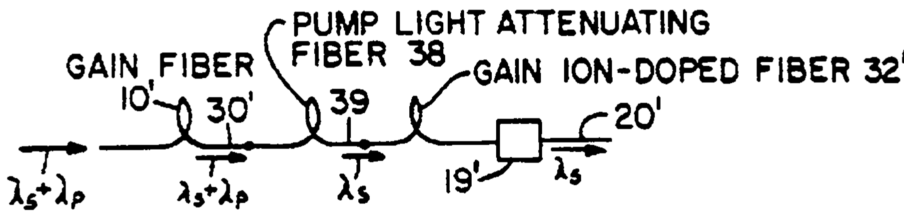


Fig. 8

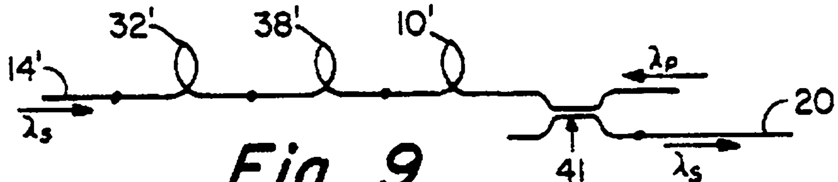


Fig. 9

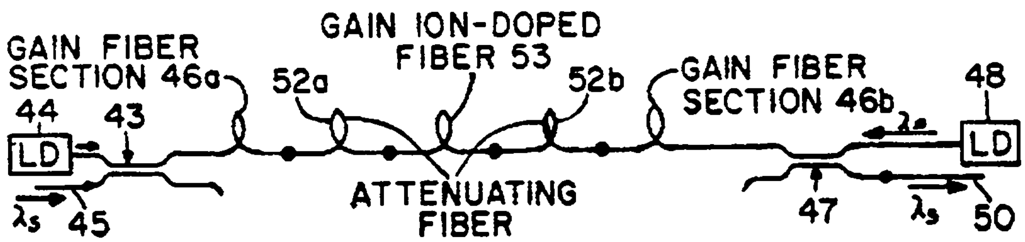
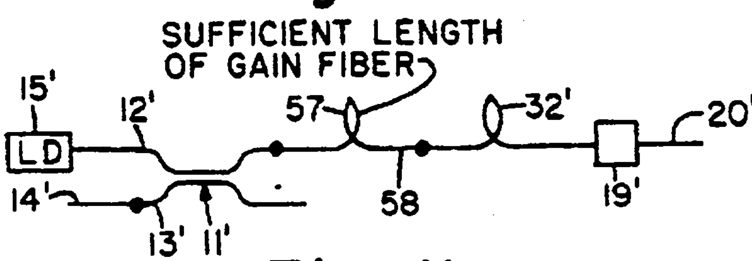


Fig. 10



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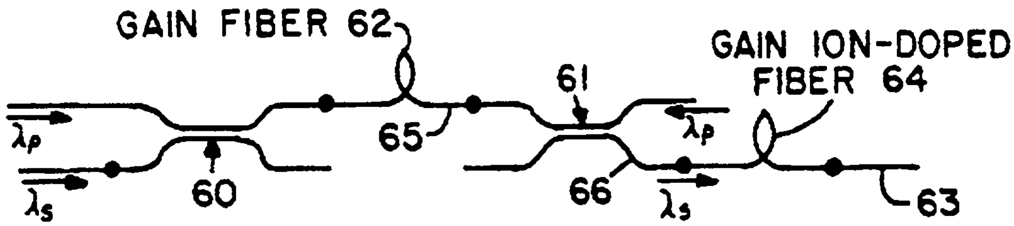

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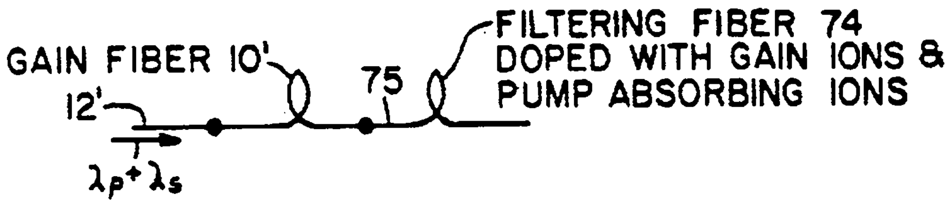

Fig. 13

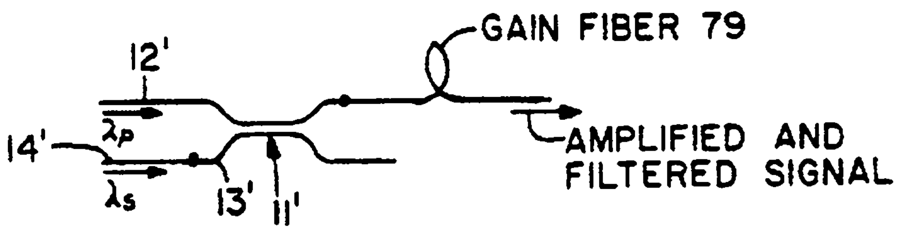

Fig. 14

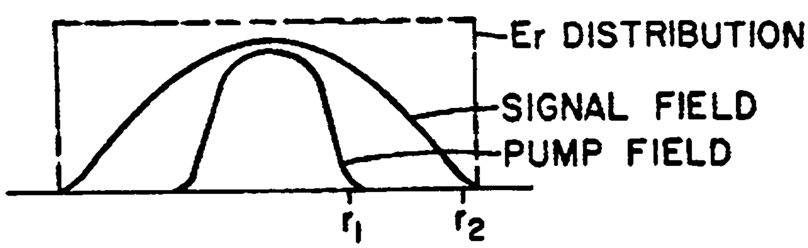

Fig. 15

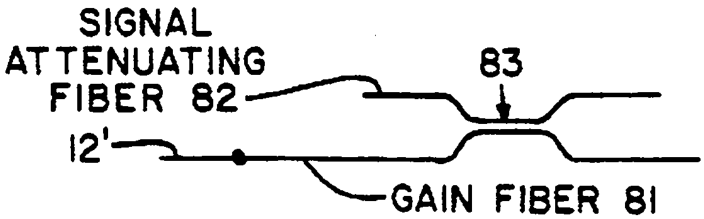

Fig. 16

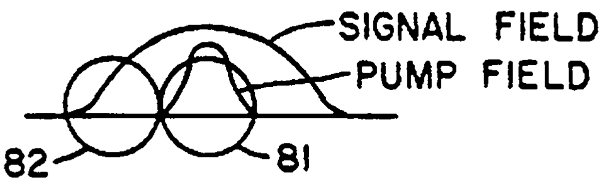

Fig. 17

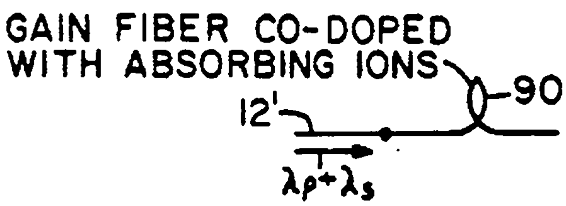

Fig. 18

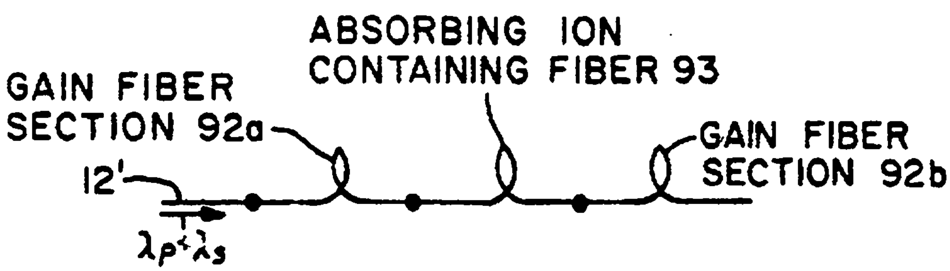

Fig. 19

DOCKET No. CORN 0002 **PATENT**

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re reissue patent application of:

Hall et al.

U.S. Patent No. 5,131,069 Issued July 14, 1992

Serial No.: 07/743,726 Group No.: 2501

Filed: August 12, 1991 Examiner: S. Barns

For: FIBER AMPLIFIER HAVING MODIFIED GAIN SPECTRUM

COMBINED DECLARATION AND POWER OF ATTORNEY BY INVENTORS

(XX) Declaration by Inventor(s):

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name; and

I verily believe that I am the original, first and sole inventor (if only one name is listed below), or an original, first and joint inventor (if plural names are listed below) of the subject matter that is claimed in letters patent **U.S. PATENT No. 5,131,069** granted on **July 14, 1992** and in the foregoing specification and for which invention I solicit a reissue patent;

ACKNOWLEDGMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims.

I acknowledge the duty to disclose all information known to be material to the patentability of this application in accordance with 37 C.F.R. § 1.56.

( ) In compliance with this duty attached herewith is an Information Disclosure Statement in accordance with 37 C.F.R. § 1.97.

STATEMENT OF INOPERATIVENESS OR INVALIDITY OF ORIGINAL PATENT 37 C.F.R. §1.175

That I believe the original patent to be

(XX) partly ( )wholly

inoperative or invalid because of error or errors, all of which were without any deceptive intent on the part of the applicant, by reason of said patent claiming

( ) more (X) less

than patentee had a right to claim.

This reissue application

( ) does (X) does not

seek to enlarge the scope of said original patent.

Errors:

[1] It was error without deceptive intent to permit U.S. Patent No. 5,131,069 to issue without having claims specifically directed to an amplifier structure having only one single-mode core.

[2] It was error without deceptive intent to permit U.S. Patent No. 5,131,069 to issue without having claims specifically directed to a fiber amplifier having a flattened gain spectrum.

DOCKET No. CORN 0002 **PATENT**

OFFER TO SURRENDER ORIGINAL PATENT 37 C.F.R. §1.178

Applicant hereby offers to surrender the original patent, the reissue of which is sought herein.

POWER OF ATTORNEY

I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

Alfred L. Michaelsen, Registration No. 24,511, and William J. Greener, Registration No. 38,165, of **Corning Incorporated**, Patent Department, SP FR 02-12, Corning NY 14831,

and Richard E. Kurtz Registration No. 19,263, Francis A. Paintin Registration No. 19,386, and Jonathan M. Waldman, Registration No. 40,861, of the firm of **WOODCOCK WASHBURN KURTZ MACKIEWICZ & NORRIS LLP**, One Liberty Place - 46th Floor, Philadelphia, Pennsylvania 19103.

( ) Attached as part of this declaration and power of attorney is the authorization of the above named attorney(s) to accept and follow instructions from my representative.

Address all telephone calls and correspondence to:

Francis A. Paintin
WOODCOCK WASHBURN KURTZ MACKIEWICZ & NORRIS LLP
One Liberty Place - 46th Floor
Philadelphia, PA 19103
Telephone No. **215-568-3100**
Facsimile No. **215-568-3439**

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

DOCKET No. CORN 0002 **PATENT**

(XX) By the inventor(s):

1	Full Name Douglas W. Hall	Inventor's Signature	Date
	Residence Corning, NY	Citizenship U.S.A.	
	Post Office Address 48 Forest Hill Drive, Corning NY 14830		
2	Full Name Mark A. Newhouse	Inventor's Signature	Date
	Residence Corning, NY	Citizenship U.S.A.	
	Post Office Address 225 Watauga Avenue, Corning NY 14830		
3	Full Name	Inventor's Signature	Date
	Residence	Citizenship	
	Post Office Address		
4	Full Name	Inventor's Signature	Date
	Residence	Citizenship	
	Post Office Address		

Note: Even though inventor(s) do not sign, complete above information for inventor(s).

DOCKET NO.: CORN 0002 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re reissue patent application of:

Hall et al.

U.S. Patent No. 5,131,069, Issued July 14, 1992

Serial No. 07/743,726 Group No.: 2501

Filed: August 12. 1991 Examiner: S. Barns

For: FIBER AMPLIFIER HAVING MODIFIED GAIN SPECTRUM

Assistant Commissioner for Patents
Washington, DC 20231

Sir:

CONSENT OF ASSIGNEE FOR REISSUE
and
ASSIGNEE'S STATEMENT OF OWNERSHIP INTEREST IN REISSUE

I. In accordance with 37 CFR §1.172(a), CORNING INCORPORATED, assignee of the entire interest in U.S. Patent No. 5,131,069, granted on July 14, 1992 to inventor(s) Douglas W. Hall and Mark A. Newhouse, hereby consents to reissue of said patent for the reasons set forth in the accompanying Reissue Declaration.

II. In accordance with 37 CFR §1.172(a), said assignee of the entire interest in United States Patent No. 5,131,069, hereby establishes assignee's ownership of said patent and its right to take action therein under 37 CFR §3.73(b) by:

(X) specifying that evidence of said ownership is recorded in the Office for each assignment in the chain of title at Reel 5817, Frame 0102-0105.

Date: June 24, 1998

CORNING INCORPORATED

By: [signature]
signature of officer

Print Name: Charles W. Deneka

Title: Senior Vice President & Chief Technical Officer